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Design for Resilient Post-Disaster Wood Waste Upcycling: The Katrina Furniture Project Experience and Its "Legacy" in a Digital Perspective

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Abstract: Wood is one of the main materials used in buildings and furniture worldwide. After a disaster, indeed, a considerable amount of timber waste is produced. Wood waste is generally downcycled—i.e., recycled into low-quality products, incinerated for energy production—or, worse, landfilled, but in a post-disaster situation, it not only represents a quantitative issue and an environmental hazard but also acquires a cultural, social, economic and emotional value, thus requiring more effective ways to be managed. The Katrina Furniture Project, led by Sergio Palleroni in 2006 for the regions hit by hurricanes Katrina and Rita, provides a valuable precedent. Through pilot initiatives in New Orleans, furniture design emerged as a resilient practice within the reconstruction process. Affected people were involved for six weeks in a collaborative design workshop, enabling the generation of income, the acquisition of professional skills and, moreover, the rebuilding of a sense of community through collective work and the intrinsic gathering value of the crafted objects. The research develops a desk analysis and an on-field survey to reflect on the social, cultural, economic and environmental impacts of this case study and on the role of furniture design for resilient wood waste upcycling. Finally, the paper discusses the "legacy" of such practices from a digital perspective, analyzing limitations and opportunities within current research in design and manufacturing.

Keywords: post-disaster; wood waste; upcycling; circularity; resilience; furniture design; digital technologies

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1. Introduction

As a renewable resource with a significative carbon-storing potential, wood is recognized as a sustainable and ecological material in the architecture and design industry, and its use is strongly advocated by the EU Green Deal [1]. In a scenario of rising demand for wood products [2,3], it must be underlined that a considerable amount of solid wood waste is generated during the construction, refurbishment, reconstruction, restoration and demolition of a wide range of timber products.

A circular approach to wood waste management should enhance reduction, reuse and recycling practices for wood debris, i.e., avoiding material downgrading and facilitating Secondary Raw Material (SRM) use, so to reduce the demand for resource extraction and extend products' and materials' life cycles.

The abovementioned conditions are further exacerbated in the case of post-disaster wood waste [4]. In such situations, a considerable volume of wood debris, varying in shape, quality and preservation, is accumulated in a very short time, failing to be recovered or reused by the industries and in a quantity far beyond the landfills capacity. In addition, post-disaster wood waste not only represents an environmental hazard but also acquires a cultural and emotional value, e.g., related to the memory of the objects and the buildings or artifacts it belongs, as well as to the natural resources and the work employed in their making.

From this perspective, this study investigates design as a potential driver for social, environmental and economic relief in post-disaster wood waste management. In particular, furniture (including, in a broader sense, furnishing, decoration and art) is here questioned as a possible "ancillary" supply chain for the upcycling of wood waste derived from post-disaster waste, for its capacity of regenerating waste into material and immaterial value-added products (social cultural, esthetic and ethic, economic).

The paper illustrates the methodology and the results of the Katrina Furniture Project, a design, teaching and philanthropic venture led by Sergio Palleroni in 2006 for the regions hit by hurricanes Katrina and Rita [5,6]. In this project, a six-weeks pilot initiative in New Orleans was carried out with the aim of helping the local communities to avoid an ecological, economic and social crisis due to the consequences of the disaster and, at the same time, create an opportunity for reconstruction, in both material and immaterial terms. With the support of humanitarian associations, universities, public and private stakeholders, local artisans and students, the collaborative design of original furniture prototypes emerged as a resilience practice for wood waste upcycling and post-emergency management. People from the affected community were involved in the project and supported in the design and construction phase, as well as in the sale of the manufactured object through the access to dedicated e-commerce platforms. In this way, the workshops supported the community in recovering from the disaster, learning professional skills and earning an income from it. As a result, the project enabled the rebuilding of a sense of community, through collective work and the intrinsic gathering value of the crafted objects.

In general, dimensionless analytical functions pertaining to the variation of functionality throughout an interest period—which includes the losses incurred during the disaster and the recovery path—are used to evaluate disaster resilience. As the concept of creating communities that are resilient to disasters becomes more widely accepted, new techniques are required that address the intricate, multifaceted aspects of resilience, such as its organizational, social, technical and economic components, and go beyond simply calculating financial losses [7]. The majority of these techniques relate to constructions and infrastructure, such as following an earthquake.

Simplified recovery functions or more intricate organizational and socio-political models can be used to estimate the recovery process, which can take many various shapes and are typically dependent on the availability of technological and human resources, societal readiness, and governmental policies. Reductions are defined as functions of system fragility, ascertained by means of multidimensional performance limit thresholds. The resilience function encompasses not only the impact of the disaster but also the outcomes of preparation, response and recovery. As a result, this feature becomes crucial for policymakers and engineering experts alike when making decisions [8].

Resilience is defined and calculated in the context of infrastructure post-earthquake recovery with the consideration of seismic resilience. It serves as an investment decision parameter for post-hazard event mitigations, emergency response plans and recovery investments on bridges. Resilience is evaluated by contrasting various configuration scenarios for structures, such as bridges [9].

In the instance of the Katrina Furniture Project, even while tangible objects made from salvaged post-disaster wood are realized, a major focus is given to foster social resilience. According to Maguire and Hanag [10], social resilience is the ability of a social entity—such as a group or community—to overcome hardship or react favorably to it. More precisely, resistance, recovery and creativity are considered to be the three characteristics of social resilience that encompass features of people's responses to disasters [11].

Resistance specifically refers to a community's attempts to endure a calamity and its aftermath. It might be interpreted as the amount of disturbance that can be tolerated without causing the community to undergo permanent transformation. The ability of a community to "pull through" a calamity is referred to as recovery. The idea of a community "bouncing back" to its pre-disaster level of functioning is strongly related to this attribute. One way to conceptualize recovery is the amount of time it takes for a community to heal from a disturbance. A community that is more resilient bounces back from a tragedy faster and more effectively, while a less resilient group takes longer to recover or may not recover at all.

Nonetheless, a perfect recovery goes beyond simply reaching the starting point of equilibrium. Rather, greater levels of functioning (and thus resilience) can be reached by adjusting to new conditions and drawing lessons from the catastrophic experience. This is a creative quality that is exemplified by an increase in resilience attained during the healing process.

In this framework, the paper looks at the Katrina Furniture Project as an example of a socially resilient post-disaster strategy. It analyzes the social, cultural, economic and environmental effects in the context and surveys its effects ten years later through site visits and interviews. This gives an overview of how the communities have become more prepared, aware and creative, particularly when it comes to reclaiming wood waste after a disaster.

The aim of the study is to investigate the Katrina Furniture Project as a design and community driven best-practice for the upcycling of wood waste in post-disaster situations. In particular, the paper analyzes the project as a scientific practice that can be generalized, scaled and repeated, thus highlighting its top-down and bottom-up inner factors inherent to the following:

- a design-based approach, actualized by collaborative workshops and made possible thanks to a system of public and private fundings (top-down);
- the mechanism of the collaborative workshops, in which unskilled communities and experts coming from different fields (academic, industry and craftmanship, design, marketing consultants, etc.) work together (bottom-up);
- the joint force of no-profit (bottom-up) and governmental (top-down) associations in the post-disaster relief, both orchestrated by an academic actor.

Within this framework, the author's objectives are to do the following:

- highlight the role of communities and social sustainability for circularity;
- define circularity not only as an economic phenomenon but as a design strategy;
- state the importance of education and culture in post-emergency situations, in which design can play an important role as a social catalyst;
- define the opportunities and limitations of the use of digital technologies in the application of such approaches.

Through site visits and interviews, this study reports on the consequences of the Katrina Furniture Project experience in the parishes of the State of Louisiana, which are still dealing with the damages of Katrina and Rita and never ceased to be affected by a natural disaster ever after that.

Finally, the paper reflects on the possible "legacy" of the project from a digital perspective, i.e., analyzes opportunities and limitations of the application of the Katrina Furniture model in the current scenario of digitalization, where digital tools can represent an added value for community recovery (new jobs, design optimization, customization) but also a barrier in terms of accessibility. The study presents selected case studies of technological innovation in advanced design and manufacturing for wood waste upcycling, in the framework of the climate and resource-related challenges in waste management. Digitally enabled innovation in design and fabrication can be pivotal in targeting post-disaster reconstruction in line with Circular Economy's goals: file-to-factory processes allow one to optimize material use, drastically reduce waste and overcome standardization constraints in favor of higher performance at no added cost [12,13].

Compared to existing literature and protocols, the novelty of this model for post-disaster waste management consists of a design- and community-driven approach, which becomes a circular and resilient experience not only through the response to an economic or environmental indicator but as a cultural and educative means to circularity as a shared social occasion. In fact, while such approach cannot provide a definitive solution to post-disaster waste, it can be crucial to leverage disaster to build a circular culture in which debris becomes a collective value. The paper consists of an introductory part, discussing the research questions and topics. Section 2 is dedicated to a focus on post-disaster wood waste management, exposing the main issues reported by international regulations. Also, the methodology of the study is presented. Section 3 examines the Katrina Furniture Project, giving attention to the methodology and the process followed by prof. Palleroni's team and focusing on the environmental, economic and social impacts. Section 4 presents the consequences of the Katrina Furniture Project in Louisiana through selected case studies in the fields of craftmanship, market and academic practice. Section 5 discusses the digital perspective for wood waste upcycling and post-disaster waste management. The illustrated research involves the use of state-of-the-art technologies, i.e., 3D Scan, Computational Design, Digital Fabrication, Artificial Intelligence and Machine Learning. Section 6 presents the results of the study and discusses the possibility to continue the Katrina Furniture Project model in a digital fashion. In the Conclusions, the study summarizes the results from an organizational, socio-economic, environmental and innovation perspective and discusses the main limitations of the research and its possible future implementations.

2. Materials and Methods

2.1. Sources and Characteristics of Post-Disaster Wood Waste after Katrina

According to the "Disaster Waste Management Guidelines" [14], post-disaster wood waste includes a heterogenous range of elements from damaged buildings and infrastructure to household furnishings; natural debris, such as trees, branches, bushes and palm tree leaves; and damaged boats, packaging materials and pallets. Nonetheless, in New Orleans after Katrina, most of the wood waste was derived from damaged buildings, with an estimated total of 75 million cubic yards of debris (about 57 million cubic meters). According to Bryan Bell of Design Corps, who participated to the project (Figure 1), these materials belonged to the distinctive New Orleans' architecture and would have vanished if not recovered. Many of these materials, in fact, have been harvested and used for more than a century before and were then irreplaceable, including the virgin cypress from local swamps and antique "barge boards". These 2-inch (about 5 cm)-thick oaks came from the sides of barges and were built in the Midwest but got scrapped after making their way down the Mississippi River to New Orleans more than a century ago. Such materials could not be simply bought again, and even if so, they would have been more than expensive [5,6].

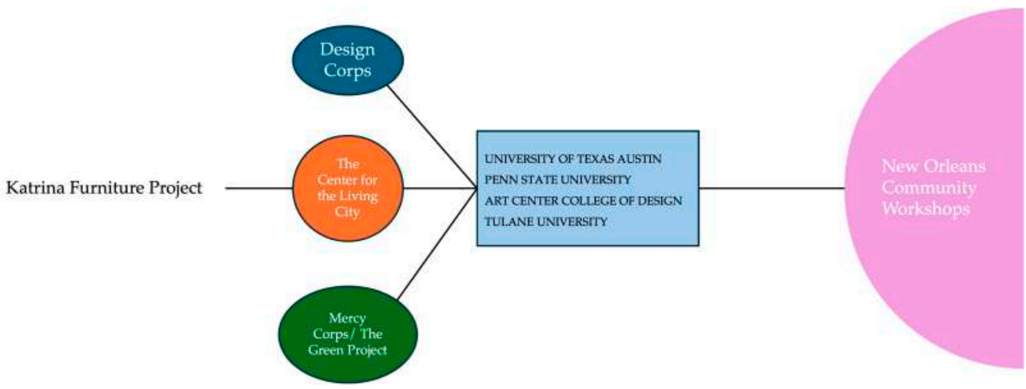

Figure 1. Katrina Furniture Project stakeholder diagram. Source: [5]. Edited by the authors.

2.2. Post-Disaster Wood Waste Management in the US

The United States has a substantial historical connection with post-disaster wood waste. Notably, Hurricane Andrew in 1992, which struck Florida, left an estimated 6 million tons of debris in the Greater Miami region. This debris included downed trees and wood remnants from approximately 150,000 severely damaged or completely destroyed houses. To address this, around 500,000 tons of wood waste resulting from the hurricane were mulched and distributed to agricultural areas, parks and residential sites [15,16].

From the year 2000 to the present, the state of Louisiana has been impacted by at least 28 tropical or subtropical cyclones. According to the Hydrometeorological Prediction Center (HPC), a tropical cyclone makes landfall along the coastline about two times every three years, and a hurricane makes landfall once every 2.8 years [17]. Hurricanes Katrina and Rita in 2005 generated approximately 75 million cubic yards of debris, with an estimated 16 million cubic yards consisting primarily of wood from the destroyed buildings [5; 34]. Subsequent hurricanes, including Hurricane Ida in 2021 and Hurricanes Zeta, Laura and Delta in the preceding years, further compounded the challenges faced by regions, such as Metro New Orleans and southwest Louisiana [18,19].

Despite the extent of post-disaster wood waste, it is just one facet of the broader issue. While the US Environmental Protection Agency (EPA) has issued guidelines for managing debris after natural disasters [20] and developed a Disaster Debris Recovery Tool [21], there is no national legislation mandating recycling in the United States [22–25]. The prospect of such regulations has consistently encountered strong opposition [26]. Consequently, a study by the US Geological Survey found that only 5% of building-related materials consumed in the US in 2000 were derived from renewable resources [27].

In the same year [26], the US EPA calculated that the renovation and demolition of buildings in the US produced 124,670,000 tons of debris annually [5]. This underscores the substantial challenges associated with post-disaster waste management and the limited emphasis on recycling within the regulatory framework.

2.3. Limits of Current Practices for Post-Disaster Wood Waste in the US

Wood is one of the main materials used in buildings and furniture worldwide. For this reason, after a natural calamity (hurricanes, earthquakes, tsunami, etc.) affecting towns or suburban areas where there is a strong presence of trees, timber debris are the prevailing typology of waste. To give some examples, after the Tohoku earthquake hit Japan in 2011, the debris were mostly composed of wood from the destroyed houses and trees dragged by the water streams originated by the subsequent tsunami [28]. The various disasters that have hit the Italian peninsula also highlight how, apart from the debris coming from forests and buildings, there is an issue concerning timber waste related to the provisional structures used during the post-disaster refurbishment, reconstruction and demolition works [29].

According to the "Disaster Waste Management Guidelines", Disaster Waste (DW) is a «well-recognized threat to health, safety and the environmental, and can also be a major impediment to post-disaster rescue operations» [14]. DW can be generated both in the immediate aftermath of a disaster and during subsequent response and recovery phases. Public health risks may emerge from various sources, including direct exposure to waste on the streets and hazardous materials, such as asbestos, pesticides, oils and solvents. Indirect risks may arise from vectors, such as flies and rodents. Additionally, dangers can manifest from the collapse of unstable structures post-disaster. The obstruction caused by DW may hinder relief and reconstruction efforts by impeding access to affected populations and areas. Environmental impacts, closely intertwined with human consequences, involve the contamination of waterways, agricultural regions and communities by chemicals and heavy metals. Physical obstacles, such as the blockage of waterways, can also occur. In numerous instances, DW exacerbates challenges for communities already grappling with the aftermath of a catastrophe.

However, DW also presents opportunities. It may contain valuable materials, including concrete, steel, timber and organic matter suitable for composting. Recognizing this value can serve as a source of income or as a reconstruction material, reducing the strain on natural resources otherwise utilized for rebuilding. Therefore, the safe handling, removal and management of DW emerge as crucial considerations in disaster response and recovery. According to the Guidelines, effective approaches should not only mitigate DW-related risks to life and health but also leverage opportunities presented by waste to facilitate recovery and promote development outcomes. In fact, current practices in post-disaster management mainly focus on removing obstacles or health risk factors related to waste but often ignore its possible value for the damaged communities.

The post-disaster activities are now being acknowledged in the literature on disaster management as a chance for communities and the country to grow.

One such possibility is the synchronization of strategic planning across several disciplines and sectors that occurs during disaster recovery [30], as described by the Institute of Medicine, Washington, DC [31]. This provides a method for involving the entire community in the redesign process. In certain situations, the abrupt destruction of physical infrastructure and disruption of systems may allow for a major restructuring of services, facilities and organizational structures in order to replace outdated arrangements that might have been preventing communities from realizing their full potential with more ideal ones.

Initiatives like 100 Resilient Cities, started by the Rockefeller Foundation, are helping cities all over the world to learn from one another and create a roadmap for becoming more resilient to the physical, social and economic challenges that arise from both sudden events (like hurricanes and earthquakes) and chronic stresses that erode community cohesion (like unemployment, overcrowded or ineffective public transportation systems, food and water shortages and violent incidents) [32].

Effective post-disaster rehabilitation and recovery can prevent impoverished communities from sliding into cyclical poverty, according to the Global Facility for Disaster Reduction and Recovery (GFDRR). Through their various stages, recovery and reconstruction offer the chance to rebuild communities for safer, more resilient and sustainable states than they were before the tragedy. Building Back Better (BBB) is a post-disaster recovery technique that strengthens community resilience to deal with physical, social, environmental and economic shocks and vulnerabilities while lowering vulnerability to future disasters. Recovering within a BBB framework allows affected communities to lower risk from circumstances and hazards that pose a concern in addition to the current hazard. Risk minimization is increasingly ingrained in development processes. However, BBB is different from development in that it places greater emphasis on making sure that recovery produces sustainable safety for communities that are more resilient than it does on filling in a nation's development gaps [33,34].

For communities and their most vulnerable members, such as women, the reconstruction phase following a disaster may present a chance [35]. From this angle, disasters act as catalysts for change, as there is a growing recognition that they present chances to steer and guide change in the direction of desired results, including equitable and sustainable development goals. Brudenls and Eakin create a unified analytical framework to make it easier to record and analyze case studies of sustainability transitions that happen after disasters. The goal is to increase the potential for theory-building and to extract lessons that can be applied to future disaster-risk mitigation. The authors do note, however, that any empirical example can pinpoint certain circumstances, assets, interpersonal relationships, and limitations that impact the transition from tragedy to sustainability [36].

This is, in turn, is the main originality trait of the Katrina Furniture Project model: waste is here considered for a role in the recovery phase, as a new "building material", both with a physical and metaphorical meaning, i.e., creating both objects and new social opportunities. Unfortunately, prevailing DW-management practices often involve either no action, allowing waste to accumulate and decompose, or improper actions, such as uncontrolled dumping (Table 1). Improper disposal may lead to long-term environmental issues affecting the community or economically significant land, necessitating additional costs for relocation.

Table 1. Typical disaster waste issues and their impacts. Source: [14] (p. 5).

Issue	Typical Human and Environmental Impacts
Uncollected building rubble from damaged buildings	Impeded access and constrained rehabilitation and reconstruction activities. Waste tends to attract more waste since the site is already considered a dumping site.
Dumping in inappropriate areas and/or proliferation of scattered dump sites	Potential human health and injury risks from dump sites too close to settlements, especially from hazardous materials. Destruction of valuable land. Impacts on drinking water supplies and damage to valuable fisheries. Additional costs if waste must be moved later. Increase in disease vectors (flies, mosquitoes, rats, etc.). Risk of waste piles collapsing. Risk of fires. Risk of cuts from sharp materials, including used syringes.
Collapse of municipal solid waste services, including possible loss of experienced waste managers	Lack of collection service and uncontrolled dumping of waste.
Uncontrolled dumping of healthcare waste from hospitals and clinics	Serious health risks to local populations, including the spread of disease and infection, for example from used syringes, odor problems.
Asbestos sheet exposure in collapsed structures or in re-use of asbestos for reconstruction	Health risks associated with inhalation.

In the case of hurricanes, typhoons or cyclones, the guidelines outline these major issues related to waste generation:

- Strong winds can tear the roof off buildings, after which walls may collapse;
- Poorly constructed houses and huts can “fold” under roof tops. Even brick and concrete walls may collapse. Waste is spread over open land, streets and marketplaces. This would include roofing materials, small items and dust carried by the wind. This may cause serious problems where asbestos is present.
- Ships and boats are often thrown ashore and destroyed, requiring specialized waste management. Vessels that sink in harbors need to be removed;
- Electrical and telephone grids, as well as transformers containing oil and PCBs, may be destroyed.

The guidelines also provide for short-, medium- and long-term phase tools and steps (Table 2).

Regarding timber and wood waste, the guidelines incorporate a waste-handling matrix outlining prevalent post-disaster waste streams. This matrix delineates potential handling and management options for both immediate and short-term actions (within the first 8 weeks of the disaster response) and medium-term actions (spanning 2–6 months after the initial phase). Notably, the UN guidelines adopt a pragmatic rather than highly technical approach, constituting a compilation of best practices derived from the expertise of seasoned disaster waste managers and existing literature. The recycling and reuse strategies outlined in the guidelines predominantly center on the incineration of wood waste for heating and cooking purposes (Table 3).

Table 2. Short-, medium- and long-term phase tools and steps in post-disaster waste management. Source: [14] (pp. 8–10).

Immediate and Short Term	
Waste needs assessment	Use this checklist to identify what different types of waste are present, where and in what condition.
Hazard ranking tool	Fill this table with all waste streams and associated hazards/risks.
Waste handling matrix	Refer to this for options on handling, treating and disposing each disaster waste type.
Medium term	
Waste needs assessment	Revisit current waste activities and ensure different types of waste are being accounted for.
Waste handling matrix	Review options for the handling, treatment and disposal of each disaster waste stream.
Fundraising	Hold consultations on the development of disaster waste management project proposals and/or funding requests.
Dumpsite closure guidelines	Use these to close unmanaged dumpsites.
Long term	
Exit strategies	Develop exit strategies and handover of disaster waste management projects.

Table 3. Waste-handling matrix for post-disaster wood waste. Source: [14] (p. 24).

Waste stream	Timber
Cash for work	Manual sorting possible
Transportation	Wheelbarrow or excavator/bulldozer offload into truck for haulage
Disposal options	If separated, reuse. Otherwise dispose at dumpsite/landfill
Recycling	Possible to separate timber for heating, cooking, shelter
Reuse	Can extract for heating, cooking, shelter

2.4. Methodology of the Study

The methodology adopted by this study is illustrated in Figure 2.

In particular, the paper examines the Katrina Furniture Project, led by Sergio Palleroni in 2006 for the regions hit by hurricanes Katrina and Rita. Affected people were involved for six weeks of circular design workshops, enabling the generation of income, the acquisition of professional skills and, moreover, the rebuilding of a sense of community through collective work and the intrinsic gathering value of the crafted objects. The study was carried out consulting original materials of the workshop and through interviews with the participants, i.e., Prof. Brad Deal (School of Design, Louisiana Tech University).

To better understand the impacts on and the consequences of the project to the territory, an on-field survey was conducted, with several site visits and interviews that were performed through four target areas in the Louisiana parishes. The cities of Ruston, Shreveport, Monroe and New Orleans were included. The people involved represent companies, small artisans, sawmills and academic practitioners that dedicate their work to post-disaster or abandoned wood waste upcycling through furniture design, furnishing manufacturing and dissemination, continuing the experience of the Katrina Furniture Project.

The on-field survey is addressed to privileged interlocutors gathered by the Louisiana Tech University Innovation Enterprise and the School of Design. The interlocutors are selected in order to cover different expertise, roles and geographic areas, so as to offer a wide range of perspectives within the Louisiana area.

Depending on the interlocutors, the analysis is structured into direct interviews, site visits or an indirect analysis from the literature and web sites. All the interviews and site visits are carried out from September to December 2023. The framework of the on-field survey is reported in Table 4.

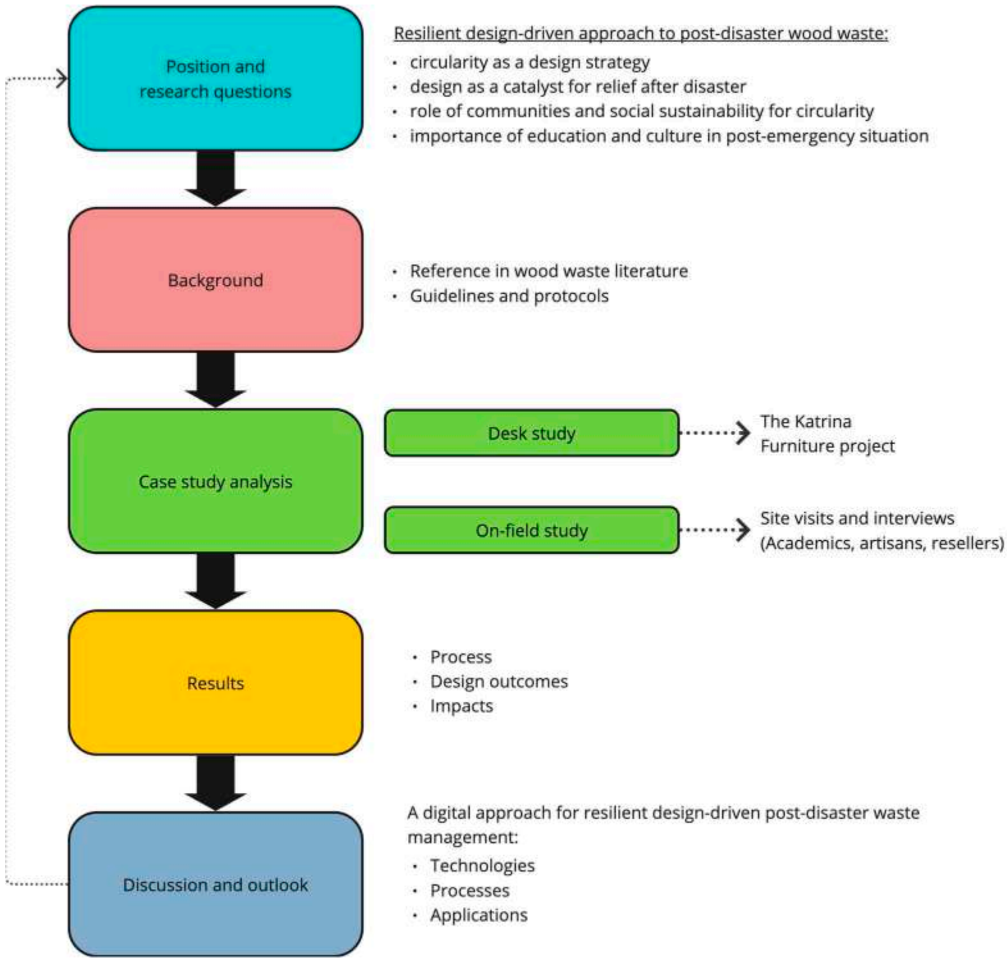

Figure 2. Flowchart of the study's methodology.

Table 4. Framework of the on-field survey.

Who	What	Where	How	Why
Charles Hoffacker	Artist	New Orleans	Site visit and indirect analysis	Reclaims post-Katrina wood to realize and sell works of art
Alex Geriner	Designer, artisan and entrepreneur	New Orleans	Indirect analysis	After Katrina, has started a design and craft company that works with reclaimed wood
Ouachita	Antiques retailer	Monroe	Site visit and indirect analysis	Sell reclaimed wood objects and furniture from post-disaster or waste
Prof. Robert Brooks	Professor and designer	Ruston	Site visit and direct interview	Holds classes and workshops on reclaimed wood design
Mike McGee	Woodworker	Shreveport	Site visit and direct interview	Collects wood from post-disaster waste to re-works and sell it

Finally, these case studies are confronted with current state-of-the-art digital practices for post-disaster timber debris upcycling in architectural and furniture design. The paper considers research advancements, both theorical and experimental, in the fields of industry 4.0 technologies for wood furniture design [37], e.g., 3D scan, Artificial Intelligence and Machine Learning and Digital Fabrication, and therefore discusses limitations of and opportunities for the use of these technologies in post-disaster situations.

3. Case Study Desk Analysis: The Katrina Furniture Project

3.1. Background

On 23 August 2005, the genesis of Hurricane Katrina occurred through the convergence of a tropical wave and the remnants of Tropical Depression Ten. Shortly thereafter, on the subsequent day, the depression escalated into a tropical storm, charting a westward course towards Florida. By 25 August, approximately two hours prior to making landfall at Hallandale Beach, it intensified into a hurricane. Following a brief weakening to tropical storm status over southern Florida, Katrina traversed into the Gulf of Mexico on 26 August, undergoing rapid intensification and reaching Category 5 hurricane status over the warm Gulf waters. However, it weakened to a high-end Category 3 hurricane at its second landfall on 29 August over southeast Louisiana and Mississippi [38,39].

The most significant loss of life resulting from Hurricane Katrina was attributed to flooding, stemming from engineering deficiencies in the flood protection system, notably the levee encircling the city of New Orleans [40]. Ultimately, approximately 80% of the city, along with extensive areas in neighboring parishes, remained submerged for weeks [16]. This inundation caused extensive destruction to transportation and communication infrastructure in New Orleans, rendering tens of thousands of residents who had not evacuated prior to landfall without adequate access to essential provisions and shelter. In response to the crisis in New Orleans, a comprehensive national and international relief effort was mobilized, involving federal, local and private rescue operations to evacuate the displaced population in the subsequent weeks. As pointed out by Frederic Schwartz, the architect elected by the planning commission of New Orleans to re-design one third of the city, the rebuilding could be the change for a reconstruction of the social justice and the community life of the city, which was itself the main goal inspiring the Katrina Furniture Project [17]. In the same year, a few months later (18–28 September), Tropical Cyclone Rita emerged. In Louisiana, Rita's storm surge affected low-lying communities across the entire coast, exacerbating the aftermath of Hurricane Katrina, including breaches in the hastily repaired levees in New Orleans. Parishes in Southwest Louisiana and counties in Southeast Texas, where Rita made landfall, experienced severe-to-catastrophic flooding and wind damage. According to a 25 October 2005, Disaster Center report, Orange and Jefferson counties in Southeast Texas saw the destruction of 4526 single-family dwellings, with an additional 14,256 dwellings sustaining major damage and 26,211 receiving minor damage.

Mobile homes and apartments also incurred significant damage or destruction (Figure 3) [41,42]. In total, nine Texas counties and five Louisiana parishes were declared disaster areas post-Rita. Electric service disruptions persisted for several weeks in some areas of both Texas and Louisiana.

3.2. Sergio Palleroni and the BASIC Initiative Design-Driven Approach

The Katrina Furniture Project grew out of an effort to recover, reuse and recycle building materials to rebuild the regions affected by hurricanes Katrina and Rita. Prior to the arrival of Prof. Palleroni's team, the city of New Orleans had already begun mass landfilling operations to get rid of the debris, only to have it inevitably become an environmental hazard for the future generations. Touring the main city streets, like Lower 9th Ward, there was an intense and shocking education to the fact that very little had been done in this area even 9 months after the storm [5,6].

Sergio Palleroni and his colleagues have worked since 1989 solving the problems of marginalized communities worldwide. In collaboration with community members, students and faculty from his program, the BASIC (Building Sustainable Communities) Initiative at the University of Texas has designed and built close to 50 schools, clinics, children's libraries, solar kitchens and housing projects, which promote the cultural sustainability of the community and the environment in which they live [5,43].

Figure 3. Hurricane Katrina impact in New Orleans, Louisiana area. Credits: The U.S. National Archives.

With Design Corps, The Hamer Center at Penn State University, Art Center College of Design and The Center for Living the City, they have shared a common belief and mission of making each project a model for making architectural education, and for that matter all design education, relevant to urgent social problems, helping communities to mobilize local resources and social capital to develop long-term sustainable practices that protect rather than erode cultural identity, dignity and stability. Their collaboration on the Katrina Furniture Project is one such case.

3.3. Aim and Methodology of the Project

The Project focuses on three priority neighborhoods, each of which has donated a public building in need of reconstruction that became a workshop. The three buildings were renovated through community-based design/build studios conducted by the University of Texas Austin, Tulane University, and Art Center College of Design in Pasadena, CA. The faculty and students collaborated with neighborhoods to design, renovate and equip the buildings for use as fully functioning carpentry and furniture workshops.

The workshops were organized as an independent not-for-profit organization and were used to train community members in the crafts of carpentry and furniture-making and in the fundamentals of operating the workshops safely and economically.

The workshops also acted as local community centers with weekend sessions to teach community members skills to rebuild their homes by providing tools and expertise. The long-term goal of the Katrina Furniture Project, in fact, was to maintain community furniture workshops that would train local employees in the craft of making furniture and, where necessary, in the fundamentals of operating these workshops.

The Katrina Furniture Project brought together experts in building deconstruction, historic preservation, building material reuse center operation and green building design. For six weeks, these individuals combined their talents to develop and build prototype furniture with the following criteria:

- The final designs would apply the highest possible standards of sustainability to the model of production, material reuse and contaminants while keeping in mind the need to educate the local communities and the end users in these principles. The group worked to maximize the potential of the available resources recovered by organizations, like the Green Project, yet recognized other competing uses for the material that may add greater value to the recovered resources;
- The final design must be cognizant of the skill level necessary to build and assemble it, enabling local community members to direct the manufacturing process with economic success, while gaining marketable skills;
- The final products must contribute to the needs of New Orleans' underserved communities and have economic viability in regional and national marketplaces.

Considering the low conservation of most materials and the difficulty in gathering relevant quantities of similar pieces, the manufacturing process was set to follows these steps:

1. Selecting the lumber;
2. Planing off the old exterior skin;
3. Cutting to appropriate widths to be fused together to form planking or structural parts;
4. Engineering the various joints;
5. Adjusting designs to perfect the aesthetics, strength and functional qualities;
6. Sanding and finishing the surfaces.

Despite being a mostly "traditional" workshop, 3-dimensional design software drawings were used to show scale and volumes and allow for free rotation viewing and judgement.

4. On-Field Survey: Wood Waste Salvaging Practices in the Louisiana Area

Louisiana is the most impacted state by billion-dollar natural disasters since 1980 (Figure 4). Extreme weather events have cost the nation nearly $2.5 trillion. Texas, Florida and Louisiana lead as the top three most impacted states at $380 billion, at $370 billion and at $290 billion, respectively.

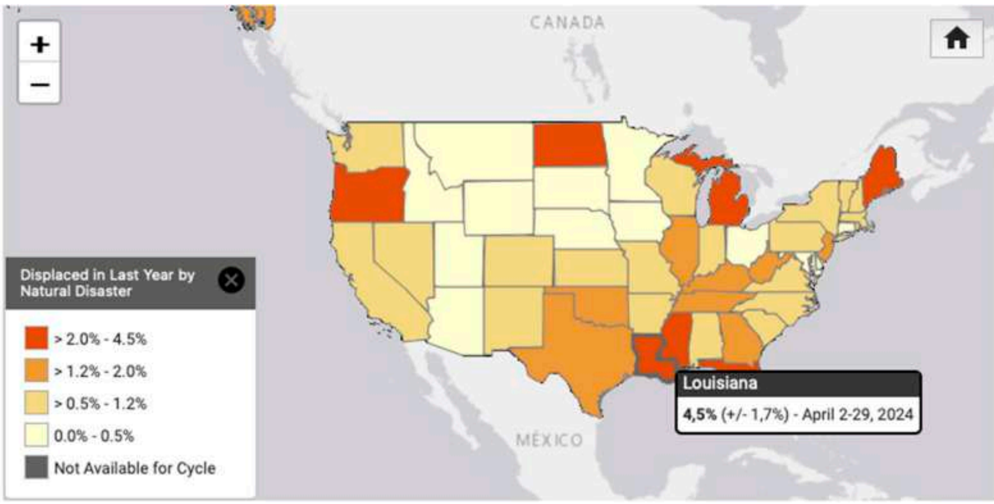

Figure 4. Share who say they were displaced in the last year because of a natural disaster. Estimates based on a survey of 63,802 U.S. households conducted 28 June to 10 July 2023. Data: Census Bureau.

Louisiana's smaller population and economy leaves the state feeling a greater impact from those costs compared to Texas and Florida. The recovery efforts after Rita and Katrina were set back by Hurricanes Laura and Delta (2020) and Hurricane Ian and Nicole (2022) [44].

As a result, only in 2023—18 years after Hurricane Katrina—all public schools in New Orleans that were damaged or destroyed during the storm have been rebuilt or restored. It is estimated that $237 million in repairs will be needed over the next 10 years [45].

In this condition of constant emergency, the establishment of resilient practices for waste recycling and upcycling are crucial to cyclically cope with material scarcity, social and economic crisis and environmental hazards. Within the TREND exchange program, in 2023, different areas of the State of Louisiana were visited with the aim of tracing the "consequences" of the Katrina Furniture Project on the territory. This research survey was performed in four target areas, where site visits and interviews were performed with artisans, merchants and educators. The results of this survey highlight how furniture, art, furnishings and architectural components design sets as a widespread post-disaster wood waste upcycling practice that helps communities reacting to natural hazards through the creation of social, cultural, educational, economic and environmental opportunities.

5. Results

5.1. Design Outcomes

The final designs were all made using refinished (replaned) 2 × 4 s recovered from hurricane-damaged New Orleans homes. It was decided that three final pieces would be designed and produced:

- Pews were to be designed for a local church that suffered considerable damage in Katrina. The pew developed would act as a case study for the reconstruction of almost 900 churches heavily damaged during hurricanes Katrina and Rita (Figure 5);
- Tables were sent to the Angel Street Community Center in Houston, Texas. This was one of four projects being built by a partnership of Habitat for Humanity and Oprah Winfrey's Angel Network. The tables would function as a connection between the permanently resettled communities and New Orleans (Figure 6);
- A simple stepstool was the prototype for the first mass-marketed object by the workshops. The stool would be sold by Design Within Reach and could be used to advertise the efforts of the Green Project and the Deconstruction for Reconstruction Project (Figure 7).

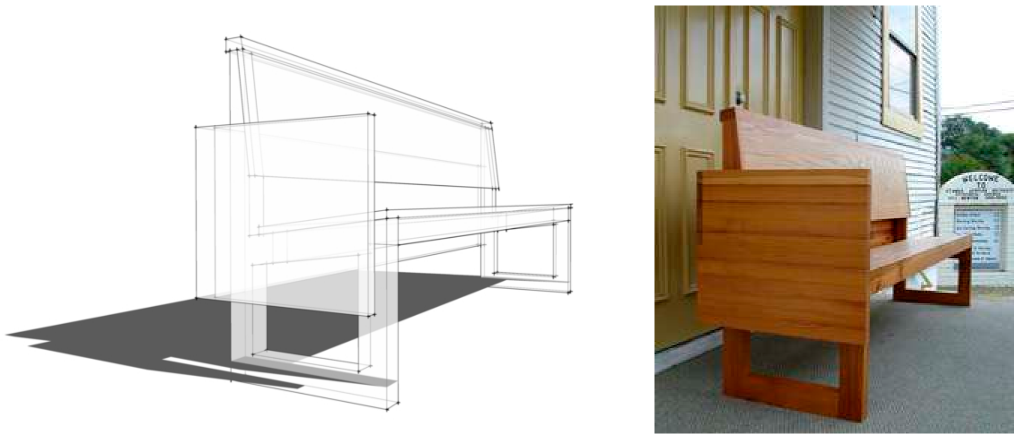

Figure 5. 3D sketched model and real prototype of the church pew. Source [46].

Through these prototypes, the project aimed at addressing issues beyond the impact of design or rebuilding, such as education, health, employment, self-empowerment and cultural identity. In fact, the Katrina Furniture Project included several activities, i.e., the following:

- The collection of economically and culturally valuable debris and post-disaster waste materials, in collaboration with the Green Project;

- The creation of a network of collaborative design wood workshops, where people were assisted by experts (designers, teachers, woodworkers) in the design and building of the prototypes, also gaining the necessary expertise to start their own activity after the disaster or to be ready to face autonomously a similar event in the future;
- The realization of furniture objects within the wood workshops;
- The activation of online market platforms to sell the furniture and provide the makers with an income.

Figure 6. 3D sketched model and real prototype of the table. Source [46].

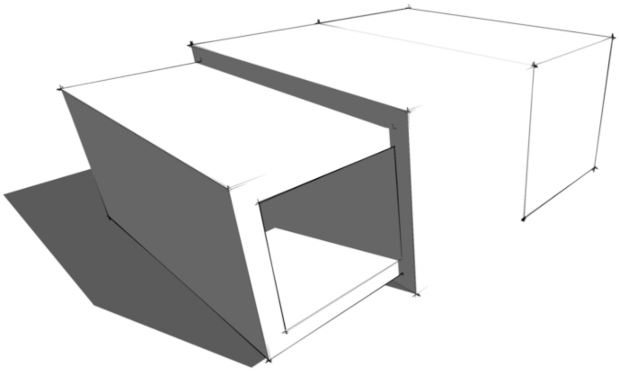

Figure 7. 3D sketched model and real prototype of the stepstool. Source [46].

The workshop took debris and exponentially increased its value, avoiding future ecological degradation of the place and providing a continuation of New Orleans' story of an innovative recovery process, creating potential means of well-being for future generations. By using salvaged materials for furniture, the Katrina Furniture Project team has contributed to an idea that can help revitalize a depressed economy, gather a lost community and divert unnecessary waste into beautiful and valuable furniture.

But the project also provided a prototype for a new system of delivery, where a series of experts, from historians to design schools to carpenters to habitat for Humanity, form a chain of expertise that could provide options in many distaste situations. The idea was to cut and paste together from these established services in a way that is both flexible and responsive to the locals but already established and ready to move fast. Unlike community "design charettes" that are a few days of experts flying into a community and then leaving, this could provide a chain of assistance that takes a community from day 1 through moving back into a best-case replacement, not a sad compromise that holds none of the culture or local qualities that existed before. By basing this chain around salvaged materials, the best case means that the materials themselves will stay around to help rebuild as well [5].

5.2. Impacts

5.2.1. Social and Cultural Impacts

The workshop aimed essentially at providing new ways and means for the post-disaster reconstruction. The affected community was placed to work side by side with people who were each in their own way a designer and architect, a student, a teacher, a furniture designer and a woodworker, to provide a rich learning and participation experience. Working with wood debris originating from destroyed buildings also poses people in front of an emotionally rich experience: every piece of wood holds a story, a narrative that must not be lost in the process. It was then their job to help show others how that story can live through furniture.

This kind of collaboration also served, to the team of Sergio Palleroni, to better target the design of the furniture pieces, continuously questioning the more viable way to create objects, both simple and sophisticated, that could be appropriated by the community.

In this sense, preserving the culture and history of a place and its people became part of the criteria for design. It was clear that the people needed some simple ways to use what was left of these homes to restart their lives and their economy and maintain a sense of pride in their history. Working with the wood from old New Orleans houses was like holding history in your hands and, instead of letting it go to a landfill, involved people who got the chance to give the old framing lumber new life, preserving in small ways the history of the city.

5.2.2. Economic Impacts

During the Katrina Furniture Project, it was estimated that the conservative labor to recover the reusable materials from approximately 30,000 houses (20% of the total estimated to be destroyed) would create 29,087 full-time jobs for one full year.

Penn State has estimated that for every 3 square feet of deconstruction, enough lumber can be salvaged to build 1 square foot of new construction. At this rate, if all of the 150,000 homes estimated to require demolition in the region after Katrina were deconstructed at a 45% recovery rate instead of demolition, this would be enough to build 50,000 new homes in the region.

Mercy Corps, the international relief organization, gave the workshops a head-start by donating $50,000 worth of furniture-grade salvaged lumber from the reconstruction of New Orleans through the Green Project [5]. Moving forward, staff from the Hamer Center at Penn State University provided training in deconstruction and salvage, insuring that much of the high-quality material from damaged buildings in the city will become new building materials and furniture. Local marketing of the workshops' products was facilitated by Ashé Cultural Arts Center and other New Orleans-based arts organizations.

Design Within Reach, the nation's largest catalog furniture company, has offered to market the furniture on a national scale.

5.2.3. Environmental Impacts

Recovered wood can be used to manufacturer value-added products, such as medium-density fiberboard and particleboard. However, these industries demand clean and consistent feedstocks, which can be difficult to achieve with wood from the post-disaster waste streams [47].

Considering post-disaster areas as a "Material Bank" [29], the project anticipated the recent speculations about Urban Mining [48] and "Non-Extractive" design applied to furniture, considering waste as a (secondary) raw material supply source, which answers current requirements of circularity and sustainability [49,50]. This is particularly crucial in the US, where each year about 33 million tons of wood-related construction and demolition debris is buried in landfills. As anaerobic microorganisms decompose this wood, it releases about 5 million tons of GHG in the form of methane gas, which is 23 times more powerful as a GHG than carbon dioxide [5].

5.3. After Katrina: Long-Term Consequences on the Territory from On-Site Surveys

5.3.1. New Orleans

Hurricane Katrina left an indelible mark on the New Orleans community; 18 years after the disaster, the wood reclaimed from the destructed homes still today holds a deep meaning for the people, and thus, it is at the center of different artistic and design initiatives aimed at salvaging wood to save its history. Post-Katrina, New Orleans has become a hub for salvaged materials, which are used to make everything from furniture to art installations to decor for restaurants and bars.

Charles Hoffacker is one of the many artisans who found, in working with post-Katrina wood waste, a way to exorcise the memories, help the community to dispose the debris and continue the culture of these materials through the time, while gaining an economic income (Figure 8). Hoffacker realized a series of 1836 paintings impressed in the wood reclaimed from homes in the 9th Ward of New Orleans. Each piece comes with a certificate of authenticity and is sold via the most widespread e-commerce platforms, i.e., Etsy, as well as, of course, to the many tourists visiting the city every day.

Figure 8. Katrina prints are sold in the open-air markets of Jackson Square, NOLA, with a certificate of authenticity reporting their origin as reclaimed wood from Hurricane Katrina. Photo by Giuliano Galluccio.

Alex Geriner, founder of Doorman Designs, created his own business working with contractors and demolition companies to turn scrap wood form hurricane-damaged buildings into headboards, tables, chairs and dressers. Some of this wood dates as far back as the 1800s, before the Civil War. The use of salvaged wood constitutes a sort of style: some pieces still have termite holes and old nails or are marked with metallic embellishments reminiscent of New Orleans's French inspired traditional designs. Each time he buys a stack of reclaimed wood, he digs up property records and any other information he can find on the house it once belonged to through the Library of Congress. The wood he used to make one of his bed frames, for instance, came from a small grocery store built in the mid-1800s and destroyed during Hurricane Katrina. He found out that the wood not only was used to build this grocery store but that it was part of an old barge. Barges floated down from the northeast in the 1800s, carrying freight to America's newly acquired land following the Louisiana Purchase [51,52].

5.3.2. Monroe

In Monroe, the Ouachita Antique Woods (OAWoods) reclaims wood waste and fallen trees, implementing a full-cycle supply chain to provide tailored furniture solutions. OAWoods is not only a full-service woodshop, but it has served as a learning center as well.

Student groups from the Louisiana Tech School of Forestry have made multiple trips over the years to learn about the operation, study the different wood species we have on-hand and explore career options in woodworking (Figure 9). People at Ouachita have mentored multiple individuals who have gone on to have successful careers in the woodworking industry.

Figure 9. Students at the School of Agricultural Science and Forestry, LATech, visiting the Ouachita Workshop. Courtesy of Prof. Dr. Nan Nan.

OAWoods has also received many accolades locally, regionally and nationally, including the feature story on the cover of BayouLife magazine, a feature interview on Louisiana Public Broadcasting's Art Rocks! Series, first place recognition in the Furniture category in Wood-Mizer's national 2021 My Wood-Mizer Project Contest and a feature on the front page of The News-Star for our work in the Joe Rogan Podcast studio.

5.3.3. Ruston

In Ruston, at the School of Design of the Louisiana Tech University, Prof. Robert Brooks holds the Interior Component Design studio and leads the Brooks + Emory design firm. In both professional and teaching practices, Brooks' focus is on waste wood salvaging and upcycling for furniture and interior design. Defining himself as a sort of "bricoleur", his approach with waste wood began in 2016, with the design and construction of a reused timber structure for a roof of an archery and paintball facility. Since then, his main source of material is from furniture and construction companies, usually not inclined to activate internal recycling processes because of the high costs and the absence of mandatory regulations.

In his experience, working with reclaimed material and saving it from landfill gives something to respond to, avoiding the "blank paper syndrome" and taking the chance to give new value to used pieces.

In his class, students are called to design and make an original piece of furniture out of wood waste, with the only mandatory requirements being to find a strong purpose and a clear function for their design. Attendants are free to work with traditional or digital tools—usually CAD softwares like Rhinoceros for bill of quantities. The use of Computer Numerically Controlled machines, available in the workshop, is not frequent, as the students would rather develop a hands-on, artisanal approach to the work. In working with reclaimed wood, consistency is one of the main challenges. In these cases, design is driven by the availability of materials, and design must be carefully developed to make sure that, during the construction phase, there are enough pieces (Figures 10 and 11).

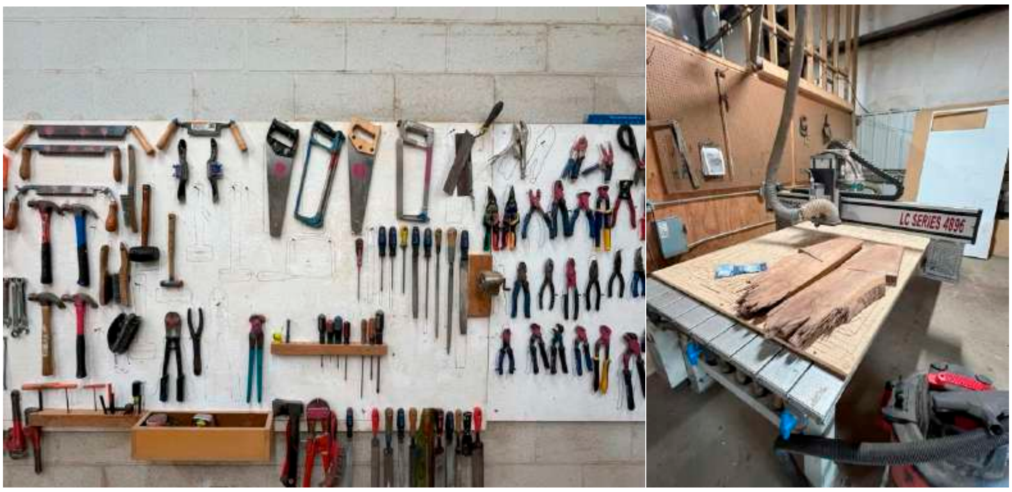

Figure 10. Louisiana Tech University's Workshop, where prof. Brooks and his students work on reclaimed wood with analogic and digital tools. Photo by Giuliano Galluccio.

Figure 11. Art and furniture prototypes realized by prof. Brooks and his students. Photo by Giuliano Galluccio.

Working with reclaimed wood means having to deal with a very unpredictable material, both in terms of performance and resource availability. With his professional practices, Brooks confronts it with an unstable market, where price fluctuations are the norm. During hard financial times, the demand for low-cost design objects from reclaimed wood is high, and thus, the availability of material is low. But, in the absence of a rooted environmental awareness and recycling culture, in good financial times, the demand for reclaimed materials and products is low: clients prefer to pay for new materials and, apart from nostalgia, there is no ethics in the choice of reclaimed materials, which rather remains a decision driven by fashion. The paradox is that an economy of recycling is based on niches: the (reclaimed) resources are going to be scarce if everyone is recycling. It is not rare, indeed, to have big companies "steal" design ideas from small artisans and workshops and sell the pieces as large-scale industrial products, repurposing design but not material approaches.

5.3.4. Shreveport

Mike McGee is the owner of the Artisan Millwork and Sawmill in Shreveport, where he works to repurpose wood/debris from demolished buildings and fallen trees into cabins and furniture material. As a one-man company, the Millwork mainly works as a subcontractor for bigger construction and design firms, providing low-cost solutions with salvaged materials from the surrounding forests after storms and hurricanes.

Beside his workshop, McGee holds a small showroom where he welcomes customers to see his handcrafted, original furniture pieces that stand as a fruit of his commitment and creativity and as a know-how that, if not continued, risks being permanently lost (Figures 12 and 13).

Figure 12. Mike McGee's Sawmill entrance in Monroe, LA. Photo by Giuliano Galluccio.

Figure 13. Reclaimed wood specimens collected by McGee and an example of a table made from a fallen tree's trunk. Photo by Giuliano Galluccio.

5.3.5. Summary of the On-Field Survey Results

To understand the impacts of the Katrina Furniture Project on the territory and its consequences in the academic, productive and social pattern of the Louisiana area, data from the on-field survey were organized in order to highlight how the following initiatives after the project are having an impact on their context, "preparing" to face future disasters.

From the survey, six categories, two per field (social and cultural; economic; environmental) emerged. In Table 5, the results are structured in relationship with the interlocutors, in particular as follows:

- From a social and cultural point of view post-disaster wood waste reclaimed can be understood as a practice to preserve the memory of the disaster and to keep a trace of the traditional materials and design that, otherwise, would go definitely lost. It also allows one to realize affordable objects and furniture;

- From an economic point of view, this approach is at the basis of new start-ups and entrepreneurial activities that employ designer and artisans. It also allows one to provide an income from value-added products, in which design empowers waste materials to become valuable objects;
- From an environmental point of view, upcycling post-disaster wood waste represents an incentive to remove waste and to adopt a circular approach to manufacturing, indirectly reducing the demand for virgin resources.

Table 5. Summary of the on-field survey results per categories.

	Social and Cultural Impacts		**Economic Impacts**		**Environmental Impacts**	
CATEGORIES	Preserves the memory of the disaster and of the traditional materials	Realizes affordable objects and furniture	Employs and/or trains artisans and designers	Creates an opportunity for an income through value-added products from waste	Removes and collects post-disaster wood waste	Adopts a circular approach to manufacturing, avoiding virgin wood supply
Artist	X			X	X	
Designer		X	X	X		X
Reseller	X	X	X	X		X
Academic		X	X	X	X	
Woodworker		X		X	X	

6. A Digital Perspective for Design with Post-Disaster Wood Waste

In post-disaster wood waste upcycling, digital furniture design can represent a viable resilient approach for both the wood originating from buildings that have been destroyed or will be demolished (floors, roofs, etc.) and the provisional structures supporting buildings awaiting restoration, which constitutes a vast and widespread catalogue of potentially reusable/recyclable material. After examining the Katrina Furniture Project and reporting the site-visits and interview from the Louisiana area, in this paper, we discuss the limitations and opportunities of a digital perspective in furniture and architectural design with post-disaster wood waste.

The cultural pervasiveness of digitalization, in fact, has touched every aspect of existence at technical, economic, social and emotional levels [53]. In architecture and design, the digital tools form an ecosystem of innovative enabling technologies that involve Computational Design, Digital Fabrication, 3D Scans, Artificial Intelligence, etc., changing the way designers communicate and collaborate, analyze and simulate, fabricate and assemble [54]. Working with wood waste, an unpredictable and unstable resource, digital technologies can help designers to grasp complex behaviors and anticipate problems, providing for a deeper understanding about materials and design.

According to the DIGIT-FUR project [37] forecasted vision for the furniture sector in 2025, digital tools will be massively used, on the one hand for mass-customization for consumers (online tools, on-demand manufacturing models, etc.) and on the other hand for digital manufacturing, from design (virtual modelling, artificial vision, etc.) to efficient manufacturing (Industry 4.0, robotics, additive manufacturing, etc.) and distribution (smart logistics, etc.). These digital tools will promote a more circular economy, making the manufacturing processes more circular (lower energy or raw material consumption, lower emissions or waste generation) and facilitating the traceability of substances, materials and products (via big data, block chain and the Internet of Things). Additionally, digital tools will facilitate informing customers about products' sustainable characteristics ("product passport"). The digitalization of the sector will affect the way products are sold, making more common the e-commerce of furniture products. This change will have a significant effect on marketing activities and the relationship with customers (communication, promotion, distribution channels, etc.) and sales and their logistic requirements (means of transport, packaging, etc.).

Nonetheless, the application of the "Circular/Digital" approach in disaster areas represents a field still subject to little analysis. The treatment of debris is an aspect that often holds back reconstruction processes [54]. However, it has been proven that effective debris management during the recovery and rebuilding phases has valuable social, financial and environmental impacts [55].

6.1. 3D Scan, Robotic Fabrication and Artificial Intelligence for Post-Disaster Wood Waste Reuse

The work of Yu and Fingrut at the UCL Bartlett School [56] provides meaningful insight into the role of digital scanning technologies for waste material control and classification. In their work, they investigated the creation of a regular and irregular wood library using the 3D scanning of waste, under-used and off-cut wood. This database was completed with the retrieval of a digital 3D model, recording its relevant parameters and physical characteristics, like the material texture. A materials database was also created in reference to the information and models (Figure 14).

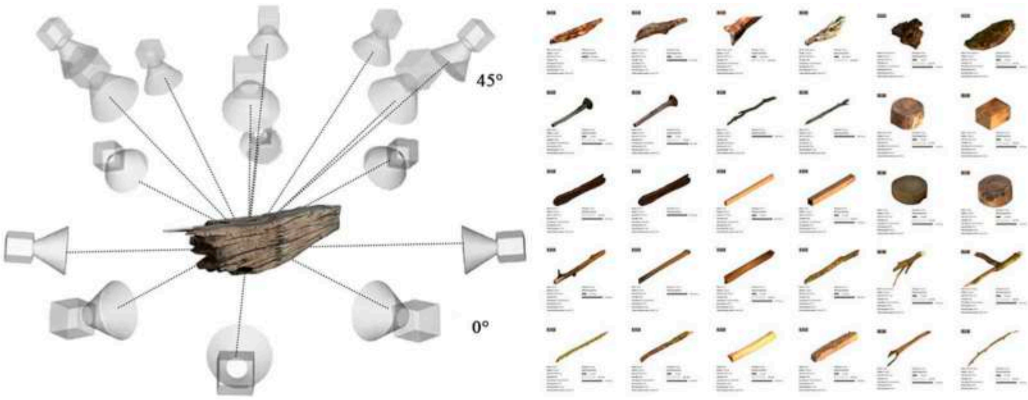

Figure 14. Wood debris scanning and material salvaged component digital library. Source: [56].

Several research projects developed at the IAAC—Institute for Advanced Architecture of Catalonia—implemented a similar workshop for furniture and architectural design purposes. In particular, the Sourced Wood [57] project aimed to utilize waste wood in constructions and reshape them as falsework structures. In their workflow, the selection of materials is of fundamental importance to drive the design and fabrication phases.

Research has substantiated that 3D scanning can complete material recovery and establish a material library. However, 3D scanning has no means to detect defects within the material, and some materials still require having their mechanical properties tested in addition to the basic inspection (Figure 15).

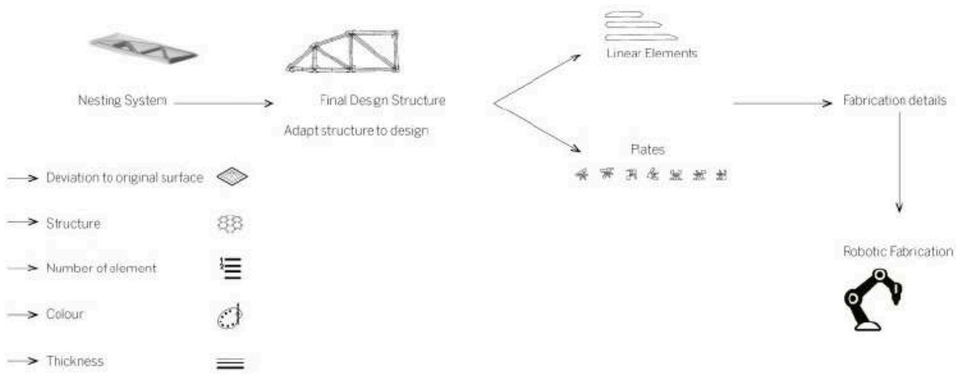

Figure 15. Sourced Wood digital workflow. Source: [57].

In this context, the application developed by the Princeton Embodied Computation Lab delved into leveraging Artificial Intelligence for instructing computers to identify knots in wood waste components, sourced from disused provisional structures and scaffolding [58]. The researchers established a user-friendly website where individuals could discern and annotate whether a given image of wood exhibited knots. Upon inputting this human-labeled data into a computer system, the Machine Learning algorithm demonstrated its capability, even in the preliminary phase, to discern the presence and location of knots. Subsequently, the identified knot locations from the computer were translated into files intended for a CNC machine tailored specifically for the fabrication of such components.

Within the ongoing DeDa (From Debris to the Dataset) research initiative conducted at the School of Architecture and Design (SAAD), University of Camerino (IT), the emphasis was placed on repurposing waste wood materials in post-disaster regions. The project applied the principles of a circular economy and Industry 4.0 to the wood waste generated from temporary structures utilized in the demolition, support and reconstruction of damaged buildings [29].

A digital workflow was established for 3D scanning, progressing to Building Information Modeling (BIM), incorporating a parametric tool designed to enhance the optimization of debris reuse within novel design solutions. The project actively engaged students through workshops and master courses, swiftly evolving into a significant platform for widespread dissemination.

6.2. Upcycling Wood Waste as a Filler in Biofabrication Processes

In recent years, biofabrication with natural fibers has perfectioned as an opportunity for wood waste upcycling, i.e., implementing design-driven processes to regenerate timber debris creating higher-value products and extending wood's life cycles. Albeit still at an experimental level, several applications demonstrate how biopolymer composites (mixtures of water, glycerol, organic binders and fillers) can be processed through 3D printing to realize full-scale architectural and design components. In these cases, wood waste is finely shredded and added to the mixture, thus overcoming general design constraints related to reclaimed wood reuse (availability, geometry, resistance). Different maintenance strategies during their use stage have already been developed to elongate their life span, while, at the end-of-life, these materials can be reused as printing matter again or left for biodegrading.

The Center for Information Technology in Architecture (CITA) at the Royal Danish Academy in Copenhagen is pioneering this kind of technology through a series of applications that involve both the field of industrial design and construction.

The "Planetary Boundaries Exhibition: Bio-Local Advanced Manufacturing", initiated by CITA, aims to conceptualize a decentralized, small-scale manufacturing process utilizing locally sourced biomaterials in Denmark [59,60]. Through the development of an innovative robotic spraying technique for a material derived from Danish waste and side-stream biomass (including beach cast eelgrass, sub-grade miscanthus and collagen glue from pigs), the research endeavors to produce experimental architectural objects and meticulously document their production chains. By systematically mapping and calculating the environmental impact of materials, machinery and transportation from their sources to the manufacturing site, the project elucidates the specific patterns and boundaries inherent to local production (Figures 16 and 17).

Figure 16. Prototype of a "3D sprayed" chair, developed at Center for IT in Architecture—CITA, Copenhagen, DK. Photo by Giuliano Galluccio.

Figure 17. 3D spraying process, developed at Center for IT in Architecture—CITA, Copenhagen, DK. Photo by Giuliano Galluccio.

6.3. Digital Fabrication Techniques and Collaborative Post-Emergency Self-Construction

The Veener House represents a humanitarian research endeavor, stemming from the aftermath of the catastrophic tsunami that struck the eastern coast of Japan in 2011. Conceived by Prof. Hiroto Kobayashi's working group, this research is driven by a digital vision wherein technological innovation catalyzes social change through sharing and active participation. The post-2011 earthquake reconstruction efforts in Japan extended beyond addressing the imminent housing crisis; they sought the establishment of a revitalized sense of community and trust. Moreover, the lack of various skilled workers, among other challenges, posed impediments to the construction industry.

In response, Hiroto Kobayashi and the team at Keio University in Tokyo conceived the idea of contributing to the reconstruction by introducing a novel construction system.

This system aimed to be not only cost-effective, rapidly deployable and lightweight but also accessible to ordinary citizens, utilizing locally sourced materials (Figure 18).

Figure 18. Veener House assembly process and final result. The wood components are designed to be lightweight and easy to assemble, in order to be joined by non-specialized workers and volunteers. Courtesy of Hiroto Kobayashi/kmdw.

In the context of this experiment, the innovative approach advocates for a low-tech architecture achieved through high-tech processes, steering clear of both technical and functional anachronisms associated with vernacular solutions. Additionally, it capitalizes on the web's capacity to foster community. While digital platforms, like Facebook, play a pivotal role as indispensable social aggregators, Prof. Hiroto Kobayashi's distinctive parametric design of the construction system for various Veener Houses (constructed in Japan, Slovenia, Burma, Nepal) is characterized by a pursuit of "simplifying complexity" [61,62].

This simplification is conveyed through stereometric geometries, which are, in turn, generated by an intricate examination of joints and connections. The goal is to facilitate the assembly of lightweight components swiftly and effortlessly, eliminating the need for hardware and minimizing material waste. For Kobayashi, the integration of digital processes is intricately tied to a meticulous process of subtraction, focusing on lightening and reducing the number of components and joints. This approach is driven by ethical responsibility, devoid of any humanitarian naivety; instead, it is the critical engagement with technology that imparts a scientific nature to this methodology [63].

From a structural point of view, this approach uses plywood panels, cut along precise axes in order to help the assembly on site, structural flexibility and resistance. Being conceived to be built in various geographical contexts, the materials used are different from place to place: anyway, the adopted structural concept is oriented towards the lowest mass and inertia to provide the highest performance under seismic stress. Compared with traditional materials and techniques, the structural efficiency of the system means it requires a minimum amount of plywood, and the use of CNC results in the best structural performance, material efficiency and simplicity of assembly (Figure 19) [64].

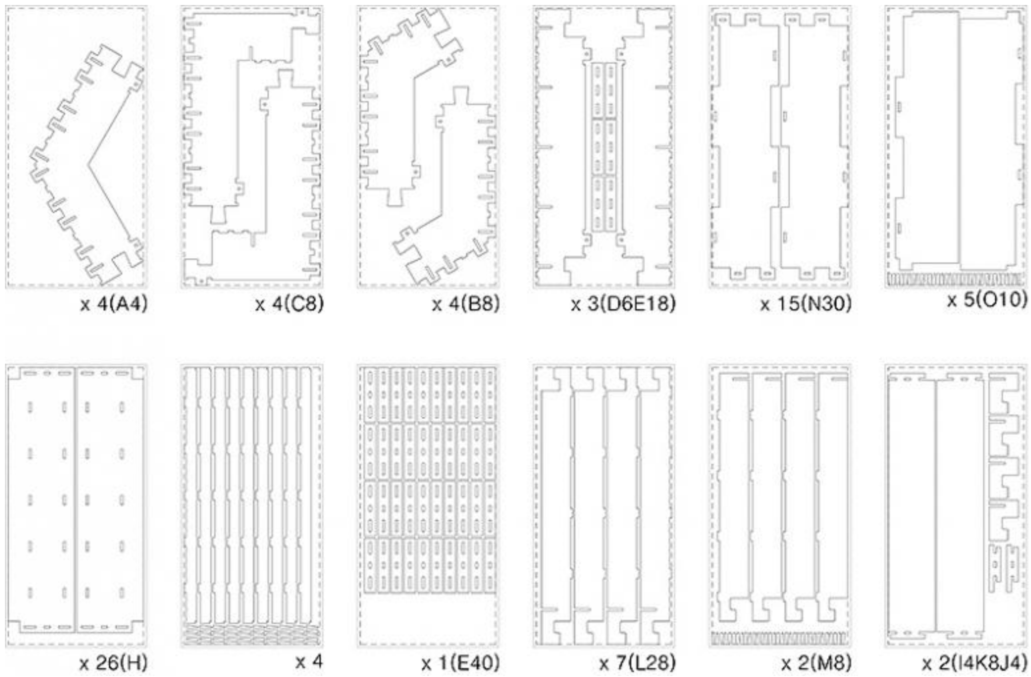

Figure 19. "Nesting" drawings of a Veener House wood panel, to be cut by CNC. Courtesy of Hiroto Kobayashi/kmdw.

7. Discussion

The paper delves into the Katrina Furniture Project and its repercussions in the Louisiana area, dissecting the analysis through desk research, on-site visits and interviews with artisans, companies and educators. Within these experiences, furniture design emerges as a resilient practice for upcycling post-disaster wood waste, fostering collaboration, circularity and economic, social, environmental and cultural sustainability. The reason behind the success of this initiative might be imputed to several factors. Furniture allows for the upcycling of waste creating small objects, easy to build even with low experience, possibly with a high economic and social value. Despite the absence of mandatory regulations on recycling or a deeply ingrained environmental culture on waste, the design of circular furniture crafted from reclaimed, salvaged wood remains today an educational, artisanal and entrepreneurial practice in these regions, cyclically affected by natural disasters.

Moreover, this approach slightly involves the use of digital technologies, especially within the more recent practices. As in the case of Geriner, this also represents an opportunity for young artisans and professionals to root into their territory and promote local economy with ethical, social and environmental values. Of course, these possibilities are enhanced by singular academic initiatives that are now promoted individually but could be in the future organized within a strategic educational framework. In the Interior Component Design studio, led by prof. Brooks at the Louisiana Tech School of Design, students are involved into the investigation of possible material practices using salvaged wood, leveraging digital technologies, as well as artisanal tools, and relying on the constant support of experts and craftsmen.

Nonetheless, current research practices are delving deeply into the technological opportunities of digitalization for wood waste upcycling. 3D scanning, digital fabrication, and Artificial Intelligence, while presenting barriers due to their complexity, also exhibit intriguing potential in wood waste upcycling and post-disaster relief. Often, these technologies are central to education and training initiatives. In certain instances, such as the Veener Houses, they serve as catalysts for social innovation activities. When specifically applied to furniture, as demonstrated by CITA, the proposed methods are effective for both creating new furniture and refurbishing damaged pieces. Importantly, these methods do not necessitate specific material properties, as they are not based on reusing materials but rather on recycling shredded waste.

The experience of a best practice for post-disaster waste management and the technological opportunities provided by digitalization can be crucial to support fragile territories to face the need to implement circular and resilient strategies, not only in emergency situations.

8. Conclusions

According to the aim of the study, the following results can be highlighted:

1. From an organizational perspective, design can act as a catalyst in a post-disaster situation and waste management in both top-down (funding acquisition, governmental association involvement) and bottom-up (no-profit involvement, local communities engagement) approaches;
2. From a socio-economic perspective, a design-driven approach to circularity is able to provide affected communities with the tool to react to the disaster and rebuild not only their places but also their lives, creating social occasions and job opportunities;
3. From an environmental perspective, community-led activities cannot themselves be enough to solve the quantitative problems related to waste management. Nonetheless, their contribution can be supportive to industry and relief organizations;
4. From an innovation point of view, digitalization provides significative possibilities to wood waste management, and its implementation within social innovation requires a novel generation of experts leading the workshops. Digital tools can also open up important job-related opportunities and can strengthen a platform-oriented approach, both for marketing and communication.

About the latter point, the main limitation of the study emerges. The analyzed application is in fact related to western countries, with the possibility to access a consolidated welfare network or no-profit and governmental funding, along with the necessary technologies. Nonetheless, considering how urgent this topic is for low-income countries—which have high rates of wood implementation for houses and commodities, as well high risks towards disaster—further studies should test the possibility of implementing this approach in other areas to verify the limits of it application and, in this case, to update this process for different contexts.

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References

1. European Commission. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal, COM(2019) 640 Final. 2019. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0640 (accessed on 1 July 2024).
2. The Food and Agriculture Organization of the UN (FAO). Forest Product Statistics. 2018. Available online: https://www.fao.org/forestry/statistics/80938/en/ (accessed on 11 February 2024).
3. Gresham House. Global Timber Outlook. 2020. Available online: https://greshamhouse.com/wp-content/uploads/2020/07/GHGTO2020FINAL.pdf (accessed on 11 February 2024).
4. Channell, M.; Graves, M.R.; Medina, V.F.; Morrow, A.B.; Brandon, D. Enhanced Tools and Techniques to Support Debris Management in Disaster Response Missions–Final Report. 2009. Available online: https://www.researchgate.net/publication/235195888_Enhanced_Tools_and_Techniques_to_Support_Debris_Management_in_Disaster_Response_Missions_Flood_and_Coastal_Storm_Damage_Reduction_Research_and_Development_Program (accessed on 11 February 2024).
5. Palleroni, S. Salvaging New Orleans. In *The Katrina Furniture Project*; Two Twelve Associates, Inc.: New York, NY, USA, 2006.
6. Hamilton, A. From Katrina Wreckage to Workshop. *Time Magazine*. 2007. Available online: https://content.time.com/time/nation/article/0,8599,1615123,00.html (accessed on 11 February 2024).
7. Chang, S.E.; Shinozuka, M. Measuring Improvements in the Disaster Resilience of Communities. *Earthq. Spectra* **2004**, *20*, 739–755. [CrossRef]
8. Cimellaro, G.P.; Reinhorn, A.M.; Bruneau, M. Framework for analytical quantification of disaster resilience. *Eng. Struct.* **2010**, *32*, 3639–3649. [CrossRef]
9. Forcellini, D. Seismic resilience of bridges isolated with traditional and geotechnical seismic isolation (GSI). *Bull. Earthq. Eng.* **2023**, *21*, 3521–3535. [CrossRef]
10. Maguire, B.; Hagan, P. Disasters and communities: Understanding social resilience. *Aust. J. Emerg. Manag.* **2007**, *22*, 16–20.
11. Kimhi, S.; Shamai, M. Community resilience and the impact of stress: Adult response to Israel's withdrawal from Lebanon. *J. Community Psychol.* **2004**, *32*, 439–451. [CrossRef]
12. Kieran, S.; Timberlake, J. *Refabricating Architecture. How Manufacturing Methodologies Are Poised to Transform Building Construction*; McGraw Hill: New York, NY, USA, 2004.
13. Carpo, M. How computers think and make. In *Craftmanship in the Digital Age. Architecture, Values and Digital Fabrication*, 4th ed.; Commerell, H.-J., Feireiss, K., Eds.; Aedes Network Campus: Berlin, Germany, 2019; pp. 32–35.
14. United Nations Office for the Coordination of Humanitarian Affairs, *Disaster Waste Management Guidelines*, 2nd ed.; UNOCHA: Geneva, Switzerland, 2013; Available online: https://wedocs.unep.org/bitstream/handle/20.500.11822/27291/DisaterWM_guidelines.pdf (accessed on 11 February 2024).
15. The Disaster Center's Tropical Storm–Hurricane Rita Page. Available online: https://web.archive.org/web/20200429151332/http://www.disastercenter.com/Tropical%20Storm%20-%20Hurricane%20-%20Rita.html (accessed on 11 February 2024).
16. Wikipedia, Hurricane Rita. Available online: https://en.wikipedia.org/wiki/Hurricane_Rita#cite_note-4 (accessed on 11 February 2024).
17. United States Environmental Protection Agency EPA. Planning for Disaster Debris, EPA Report. 1995. Available online: https://archive.epa.gov/epawaste/inforesources/web/pdf/dstr-pdf.pdf (accessed on 11 February 2024).
18. CRS Report for Congress. Disaster Debris Removal After Hurricane Katrina: Status and Associated Issues. 2008. Available online: https://sgp.fas.org/crs/misc/RL33477.pdf (accessed on 11 February 2024).
19. Wells, C.K.; Sparber, S. Louisiana Had the Worst Natural Disaster Displacement in the Country Last Year. *AXIOS New Orleans*. 2023. Available online: https://www.axios.com/local/new-orleans/2023/08/11/louisiana-residents-displaced-hurricanes (accessed on 11 February 2024).
20. United States Census Bureau. Household Pulse Survey. 2023. Available online: https://www.census.gov/data-tools/demo/hhp/#/?measures=DISPLACED (accessed on 11 February 2024).

21. United States Environmental Protection Agency. Managing Debris after a Natural Disaster. 2023. Available online: https://www.epa.gov/natural-disasters/managing-debris-after-natural-disaster (accessed on 11 February 2024).
22. 42 U.S.C. §6901 et seq., Resource Conservation and Recovery Act. 1976. Available online: https://www.epa.gov/laws-regulations/summary-resource-conservation-and-recovery-act (accessed on 1 July 2024).
23. United States Environmental Protection Agency. U.S. State and Local Waste and Materials Characterization Reports. Available online: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/us-state-and-local-waste-and-materials (accessed on 11 February 2024).
24. United States Environmental Protection Agency. The U.S. Recycling System. Available online: https://www.epa.gov/circulareconomy/us-recycling-system (accessed on 11 February 2024).
25. Wikipedia, Recycling in the United States. Available online: https://en.wikipedia.org/wiki/Recycling_in_the_United_States (accessed on 11 February 2024).
26. O'Donnell, C.; Pranger, D. *The Architecture of Waste: Design for a Circular Economy*; Routledge: London, UK, 2020.
27. Tierney, J. Recycling is Garbage. *New York Times* **1996**, *6*, 24.
28. Wikipedia, 2011 Tohoku Earthquake and Tsunami. Available online: https://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami (accessed on 11 February 2024).
29. Ruggiero, R.; Cognoli, R.; Cocco, P.L. From Debris to the Data Set (DEDA): A Digital Application for the Upcycling of Waste Wood Material in Post Disaster Areas. In *Architecture and Design for Industry 4.0. Theory and Practice*; Barberio, M., Colella, M., Figliola, A., Battisti, A., Eds.; Springer: Cham, Switzerland, 2024; pp. 807–836.
30. Committee on Post-Disaster Recovery of a Community's Public Health, Medical, and Social Services; Board on Health Sciences Policy; Institute of Medicine, Washington (DC). *Post-Disaster Opportunities to Advance Healthy, Resilient, and Sustainable Communities. Healthy, Resilient, and Sustainable Communities after Disasters: Strategies, Opportunities, and Planning for Recovery*; National Academies Press: Cambridge, MA, USA, 2015.
31. Nolen, A. *A Health in All Policies Approach to Disaster Recovery: Lessons from Galveston*; IOM Committee on Post-disaster Recovery of a Community's Public Health, Medical, and Social Services: Washington, DC, USA, 2014.
32. 100 Resilient Cities. Available online: http://www.100resilientcities.org/pages/about-us (accessed on 1 July 2024).
33. Global Facility for Disaster Reduction and Recovery (GFDRR). Building Back Better in Post-Disaster Recovery. Available online: https://www.gfdrr.org/sites/default/files/2017-09/Building%20Back%20Better%20Guidance%20Note_0.pdf (accessed on 1 July 2024).
34. Clinton, W.J. Key Propositions for Building Back Better: Lessons Learned from Tsunami Recovery. In *Office of the Secretary-General's Special Envoy for Tsunami Recovery*; United Nations: New York, NY, USA, 2006.
35. Thurairajah, N.; Amaratunga, D.; Haigh, R. Post disaster reconstruction as an opportunity for development: Women's perspective. In Proceedings of the CIB W89 International Conference on Building Education and Research (BEAR), Dambulla, Sri Lanka, 11–15 February 2008.
36. Brundiers, K.; Eakin, H.C. Leveraging Post-Disaster Windows of Opportunities for Change towards Sustainability: A Framework. *Sustainability* **2018**, *10*, 1390. [CrossRef]
37. DIGIT-FUR. Impacts of the Digital Transformation in the Wood Furniture Industry Final Document. Available online: https://digit-fur.eu/documents/ (accessed on 11 February 2024).
38. Katrina Meteorology and Forecasting. Available online: https://hurricanescience.org/history/studies/katrinacase/storm/index.html (accessed on 11 February 2024).
39. Knabb, R.D.; Rhome, J.R.; Brown, D.P. Tropycal Ciclone Report Hurricane Katrina. 2023. Available online: https://www.nhc.noaa.gov/data/tcr/AL122005_Katrina.pdf (accessed on 11 February 2024).
40. Campbell, R. Decade After Katrina, Pointing Finger More Firmly at Army Cops. The New York Times. 2015. Available online: https://www.nytimes.com/2015/05/24/us/decade-after-katrina-pointing-finger-more-firmly-at-army-corps.html (accessed on 11 February 2024).
41. Plyer, A. Facts for Features: Katrina Impact. 2016. Available online: https://www.datacenterresearch.org/data-resources/katrina/facts-for-impact/ (accessed on 11 February 2024).
42. City of New Orleans. UNOP–The Unified New Orleans Plan. Citywide Strategic Recovery and Rebuilding Plan. 2007. Available online: https://abag.ca.gov/sites/default/files/new_orleans-final-plan-april-2007.pdf (accessed on 24 May 2024).
43. Basic Initiative Website. Available online: https://www.spatialagency.net/database/basic.initiative (accessed on 11 February 2024).
44. Wells, C.K. New Orleans Finally Completes Post-Katrina School Restoration Project. Available online: https://www.axios.com/local/new-orleans/2023/05/14/new-orleans-hurricane-katrina-schools-rebuild (accessed on 11 February 2024).
45. Cooper Hewitt, Katrina Furniture Project. Available online: https://collection.cooperhewitt.org/objects/420778853/images/ (accessed on 12 February 2024).
46. Matos, G.R. *Materials Flow in the United States—A Global Context, 1900–2020*; No. 1164; US Geological Survey: Reston, VA, USA, 2022. [CrossRef]
47. Cossu, R.; Salieri, V.; Bisinella, V. *Urban Mining: A Global Cycle Approach to Resources Recovery from Solid Waste*; CISA Publisher: Padova, Italy, 2012.

48. Wigley, M. Returning the Gift: Running Architecture in Revers. In *Non-Extractive Architecture. On Designing without Depletation*; Korody, N., Ed.; Stenberg Press: Berlin, Germany, 2021; pp. 41–58.
49. Rigillo, M.; Russo Ermolli, S.; Galluccio, G.; Piccirillo, S.; Tordo, S.; Galdi, F.; Musto, M. A process "algorithm" for C&D materials reuse through file-to-factory processes. *Environ. Res. Technol.* **2022**, *5*, 340–348.
50. Adams, J. 15 Years After Katrina, A Look at the New Orleans Design Scene. Architectural Digest. 2020. Available online: https://www.architecturaldigest.com/story/15-years-after-katrina-a-look-at-new-orleans-design-scene (accessed on 11 February 2024).
51. Poon, L. A Designer Finds New Life in the Rubble of Hurricane Katrina. 2015. Available online: https://www.bloomberg.com/news/articles/2015-12-02/doorman-designs-furniture-maker-turns-hurricane-katrina-rubble-into-furniture (accessed on 11 February 2024).
52. Picon, A. *The Materiality of Architecture*; The University of Minnesota Press: Minneapolis, MN, USA, 2020.
53. Tamke, M. Foundamental changes for architecture. In *Craftmanship in the Digital Age. Architecture, Values and Digital Fabrication*, 4th ed.; Commerell, H.-J., Feireiss, K., Eds.; Aedes Network Campus: Berlin, Germany, 2019; pp. 36–39.
54. The Associated Press. Where Will Garbage from KATRINA Clenaup Go? NBC News. 2005. Available online: https://www.nbcnews.com/id/wbna9375252 (accessed on 12 February 2024).
55. Falk, R.H.; McKeever, D.B. Recovering Wood for Reuse and Recycling: A United States Perspective. In *Management of Recovered Wood Recycling, Bioenergy and Other Options*; Christos, G., Ed.; University Studio Press: Thessaloniki, Greece, 2004.
56. Yu, B.; Fingrut, A. Sustainable building design (SBD) with reclaimed wood library constructed in collaboration with 3D scanning technology in the UK. *Resouces Conserv. Recycl.* **2022**, *186*, 106566. [CrossRef]
57. Advanced Robotic Fabrication: Sourced Wood. IAAC Blog. Available online: https://www.iaacblog.com/programs/sourced-wood/ (accessed on 11 February 2024).
58. Gerfen, K.; Embodied Computation Lab. Architects Magazine. 2018. Available online: https://www.architectmagazine.com/project-gallery/embodied-computation-lab_o (accessed on 11 February 2024).
59. Thomsen, M.R.; Tamke, M. Towards a transformational eco-metabolistic bio-based design framework in architecture. *Bioinspir. Biomim.* **2022**, *17*, 045005. [CrossRef]
60. Nicholas, P.; Lharchi, A.; Tamke, M.; Goudarzi, H.V.; Eppinger, C.; Sonne, K.; Rossi, G.; Ramsgaard Thomsen, M. A Design Modeling Framework for Multi-Material Biopolymer 3D Printing. In *Advances in Architectural Geometry*; Dorfler, K., Knippers, J., Menges, A., Parascho, S., Pottmann, E., Wortmann, T., Eds.; De Gruyter: Berlin, Germany, 2023; pp. 193–206.
61. Veener House Project Website. Available online: www.veneerhouse.com (accessed on 11 February 2024).
62. Galluccio, G. Veener House. In *The Digital Culture of Architecture*; Russo Ermolli, S., Ed.; Maggioli: Santarcangelo di Romagna, Italy, 2020; pp. 178–181.
63. Veneer House Partecipatory Architecture Project Publication. Available online: https://issuu.com/veneerhouse/docs/veneer-house-inc_en_print (accessed on 26 May 2024).
64. Hudert, M.; Sven Pfeiffer, S. *Rethinking Wood: Future Dimensions of Timber Assembly*; Birkhauser: Basilea, Switzerland, 2019.